

Location Dependency and Antenna / Body / Sensor-lead Interaction Effects in a Cell-phone Based GSM 1800 Telemedicine Link

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Abstract-The error-free requirement of today's cell-phone based telemedicine systems demands investigations into the potential causes of service degradation. Measuring the Received Signal Strength Indication (RSSI) level at an 1800 MHz handset, it was found that building construction parameters and multiple- and single-body effects may all negate the monitoring objectives. Furthermore, FDTD simulations revealed the effect that sensor-leads passing close to the handset's antenna can have on system performance. Changes in lead orientation in the near field of the radiating unit (cell-phone & antenna) result in profound differences in the far field patterns. This is attributed to the biphasic nature of the Conduction Current Density (J) distribution typically found along the wire/s emanating from the handset. J distribution is dominated by the magnetic coupling component in the near field region; an increased separation between the antenna and the sensor lead results in a smaller coupled current, and a consequent rise in system efficiency.

I. INTRODUCTION

The increasing need for remote vital-signs monitoring in applications such as the care of post day-surgery patients recovering at home [1] or in emergency trauma signalling from accident sites has resulted in the growth of telemedicine [2]. PSTN lines, private radio networks and UHF cellular telephony systems are the principal means of human vital-sign transmission for remote expert analysis. The basic parameters that may be transmitted range from simple heart rate, blood pressure and body temperature, to full-bandwidth ECG waveforms and blood glucose measurements, the latter being an essential parameter in the care of diabetic patients.

A home-care telemetry link must provide continuous, error free operation, whereas in normal telephony an element of dropout may be tolerated. Cellular networks such as GSM 900 and DCS 1800, ITS 1900 and third generation (3G) systems may experience significant service outage because the user's environment may differ from what is normally met in cellular telephony. Therefore, reliability problems may arise because of in-building propagation effects, nearby pedestrian traffic and body/antenna/sensor-lead interaction, all leading to weak signal provision.

II. SIGNAL STRENGTH DEPENDENCY

A. Location dependency

Slow-fading measurements revealed that exact terminal location within a building (a micro-constructional parameter), as well as whether the radio is operating in a rural or urban environment, has a strong influence on link performance. Furthermore, an increased number of constructional obstructions in any building generally raised path attenuation and lowered the received signal strength indication (RSSI), compared to an outside measurement. Typically, losses of 8 and 4 dB per floor were measured in rural and urban buildings, respectively, in and around Athens, Greece. The highly-reinforced concrete construction widely used in Greece (due to seismological activity) produces, on average, 3-5 dB higher attenuation from outside-to-inside a building, compared to that found in the U.K.

Macro effects. Representative temporal variation measurements (made with a calibrated cell-phone loaded with data logging software, sampling at 8 samples/sec) were used to characterise reception at ground level along the outer perimeters of buildings located in rural and urban areas of Athens.

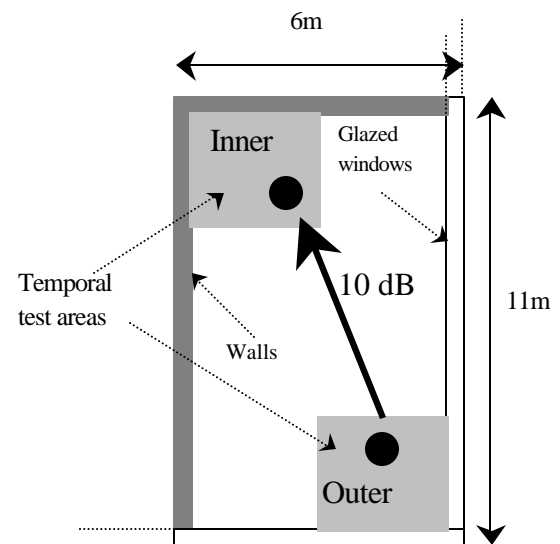


Fig. 1: A ground floor store in Athens, with two fully glazed walls, shows a slow fading reduction of 10 dB, outer-to-inner.

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Measurements were conducted under ‘low-density’ pedestrian traffic conditions (less than 10 people/m²). The more dynamic nature of the urban location, principally due to localised vehicle movements, produced RSSI fluctuations of 20-25 dB, compared to the more stable rural location where signal variations rarely exceeded 14 dB.

Micro effects. As noted from deterministic models developed to investigate the outdoor-to-indoor propagation path in cellular systems [7], our measurement campaign has indicated an ‘outer-to-inner’ signal dependence within large rooms in buildings. An ‘inner’ region is classified as any part of a room greater than 2.5 m from an opening (window or door). In the ground floor store shown in Figure 1 the reduction in measured mean signal level was 10 dB under static conditions.

B. Pedestrian traffic dependency

‘Pedestrian traffic’ can enormously affect the RSSI level in indoor environments. In a recent SISP model to predict propagation in an indoor-only channel [6], it was calculated that the combined effect of moving people and a mobile terminal caused rapid fading, up to 30 dB. This was based on a dual image and ray-shooting approach. As stated in [1], the fading profile due to ‘low-density’ traffic can be approximated by a Rayleigh distribution. Averaging over a number of measurements in various ‘inner’ apartment regions, the CDF comparison plotted in Figure 2 shows the vulnerability of the received signal to ‘high-density’ traffic. The distributions are Rician, with different k factors. The difference in mean RSSI levels between ‘high’ and ‘low’ density pedestrian traffic was up to 8 dB.

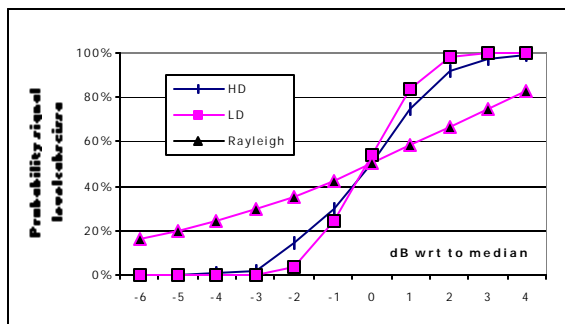


Fig. 2: Averaged CDF illustrating the effect of ‘high’ and ‘low’ density pedestrian traffic in an inner apartment region. Note the departure from a Rayleigh characteristic.

III. WIRE-BODY IMPLICATIONS

A. Body fading effect implications.

Body / cell-phone antenna interaction. The body-shadowing effect found when a cellular telephone is held close to the user’s head is well known and validated [3], [4] and [5]. However, in a telemedicine application, the handset must operate effectively when body-worn at waist height, a convenient location for fixed use over 24-72 hours – a likely monitoring period – and allow the routing of cables to biomedical signal acquisition modules, as shown in Figure 3. Under these conditions the shadowing can be investigated either by using numerical techniques such as FDTD, or by measurements. It has been quantified in [1] that the attenuation due to body presence is in the range 20-30 dB. This has been confirmed by measurements where two types of attenuation – ‘proximity’ and ‘through-body’ have been distinguished. The overall attenuation depends on the subject’s location, whether indoors or outdoors; in the latter, through-body loss appears larger because of the reduced number of localised reflections that reinforce the received signal.

B. Body / antenna / sensor-lead interaction.

Sensor-lead coupling to cell-phone antenna. Using commercial FDTD code [8], a cell-phone placed at waist height was found to be 33.5 % efficient, compared to its ‘free-space’ equivalent. Figure 3 shows the azimuthal polar patterns resulting from an 1800 MHz $\lambda/4$ monopole mounted on a conducting enclosure of cell-phone dimensions and placed at waist height on an adult-male.

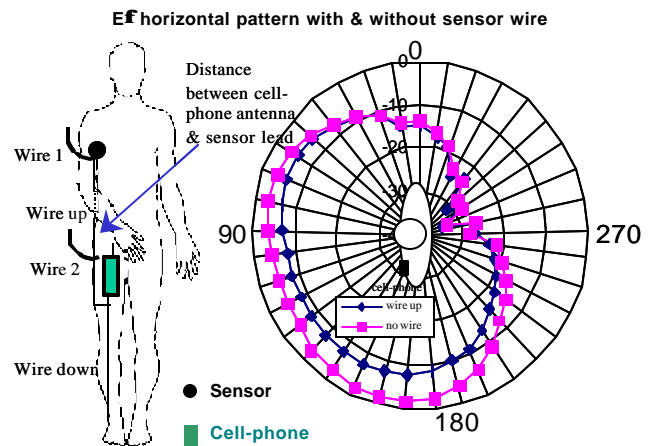


Fig. 3: Azimuthal polar patterns produced when a cell-phone transmitting at 1800 MHz is placed at waist-height (using FDTD modelling). Note the ‘through-body’ null. Close proximity of the sensor-lead to the handset’s antenna is a potential source of service degradation.

E_θ azimuthal plots, comparing the effect of wires 1 & 2

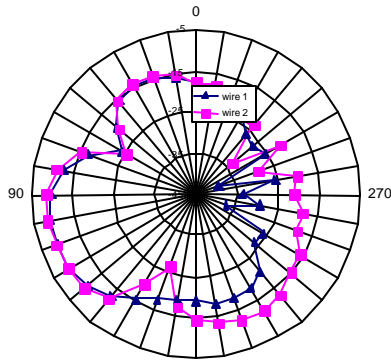


Fig. 4: E_θ , azimuth polar pattern reveals a difference of 10-15 dB in the backward direction when wire 2 is introduced in the antenna's near field, compared to a wire 1 placed well away from that field, following the geometry of Figure 3.

The inclusion of a sensor at the subject's axilla for body temperature acquisition and the subsequent sensor-lead running to the handset's 'hands-free' input port further degraded the cell-phone's efficiency to about 10 %; the modified polar pattern for this 'wire up' situation is also shown in Figure 3. This is an example of combined magnetic and conductive coupling of radio frequency (RF) energy to the sensor lead: the latter then acts as an additional radiator, modifying the final polar pattern produced. Magnetic current is induced directly through near-field coupling when the sensor lead is deployed close to the antenna (the spacing was 5-20 mm here), while RF current can be conducted along the lead from the basic radiating system comprising the antenna-plus-handset. Conductive coupling only, with the wire suspended from the bottom of the handset, did not produce profound differences in this instance. The pattern found was virtually identical with that of the waist-worn handset operating without an additional wire, giving a radiation efficiency of 33.7 %.

Extended leads may be required for wide sensor deployment on the body: with an effectively random distribution possible, the resultant polar patterns require investigation. Two separate test extensions are shown in Figure 3, with a wire going round the arm (wire 1), and a further one (wire 2) circling the waist. There is a well-defined difference in the E_θ horizontal patterns produced by these two new lead configurations, as illustrated in Figure 4. With wire 2 fitted the front-to-back ratio of the radiating system is decreased, giving a more omni-directional polar pattern that compensates for body proximity losses.

Looking closely at the single-wire connection extending from the handset to the axilla, as shown in Figure 5, the wire may be separated into 3 regions;

regions 1 and 2 are in the near field of the radiating unit comprised of the conducting box and the $\lambda/4$ monopole. The near field extent R is approximated by:

$$R = \frac{2L^2}{\lambda} \quad (1)$$

where L is the diameter of the smallest sphere that completely encloses the radiating system.

FDTD simulation of the conduction current density (J) gives an estimation of the current that potentially will flow in the wire, enabling the characteristic standing wave to be plotted. Figure 6 shows J (A/m^2) versus distance from the connection point at the cell-phone (in wavelengths, λ) for a variety of sensor-lead / antenna geometries, as follows:

- (i) magnetic and conductive coupling – the 'wire-up' layout in Figure 3;
- (ii) conductive coupling only – 'wire-down' in Figure 3;
- (iii) magnetic coupling only, with the sensor lead disconnected from the handset.

Free-space, half-wavelength distance markers are shown for comparison purposes. Magnetic coupling dominates in this series of simulations, producing characteristic biphasic J steps from the near field (regions 1 & 2), to the far-field (region 3). An increased antenna / wire separation still gave the biphasic shape, but with reduced emphasis in the near field.

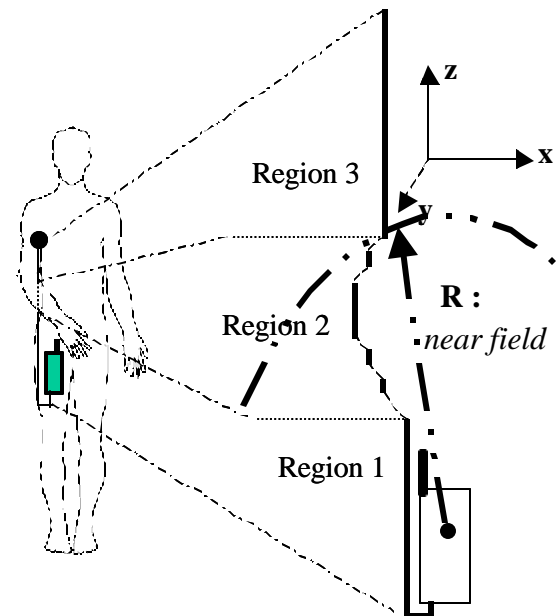


Fig. 5: Lead geometry separated into 3 discrete regions, with the first two located in the near field of the handset antenna. Note that region 2 lies under the arm.

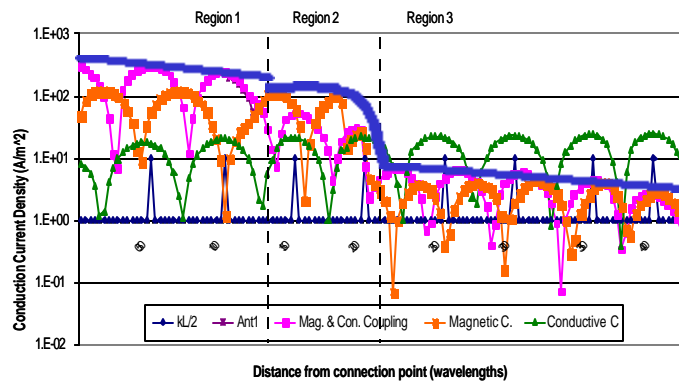


Fig. 6: Sensor-lead current density distributions, illustrating the dominance of magnetic coupling when a wire passes 5 mm from an energised monopole antenna.

Body tissue effect on standing wave. In Figure 6 the peak magnitude of the conduction current profile increases further away from the connection point. This happens because the separation between the suspended wire and biological tissue rises, with a subsequent reduction in interaction. When the wire-body separation is constant, peak J remains constant.

For the 'wire-up' case, the standing wave is a superposition of the magnetic and conductive components. The significance of biological tissue is particularly important here, when considering that the lead passes between the abdomen and an overlaid lower arm: Region 2 in Figure 5. The localised reduction in dielectric constant, along with the lead changing direction (a property that also produces current reflections), accounts for the wavelength shortening – or reduction in current-peak spacing - in this region.

IV. CONCLUSIONS

From the range of theoretical and practical observations discussed above, it may be deduced that reliability in 1800 MHz cellular telemedicine systems can be affected by:

- 1) In-building signal penetration due to the constructional materials and design used, plus almost certain system failure for situations requiring operation below ground in, for example, basements.
- 2) Micro- and macro-effects in buildings (both urban and rural), including the 'outer-to-inner' fading phenomena noted in large rooms.
- 3) Slow fading caused by pedestrian human traffic passing in proximity to the handset, resulting in increased signal fluctuation in the 'outer' regions of enclosed spaces.

4) Direct interaction between the user's body and the antenna, performance dependent on user orientation (whether sitting, lying, or standing); losses of up to 30 dB have been measured.

5) A wire magnetically and conductively coupled to the cell-phone antenna can lead to substantial polar pattern distortion.

6) Appropriate lead placement in the near field of the antenna could reduce the forward gain, but associated decreases in front-to-back ratio enhance system omni-directionality.

7) System efficiency depends highly on sensor-lead / cell-phone / antenna separation. For increasing separations, an improvement in radiation efficiency is seen.

8) The magnetic component dominates over the Conduction Current Density magnitude compared to the conductive component.

ACKNOWLEDGEMENT

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